Optimization of Battery Storage Capacity with Min-Max Power Dispatching Method for Wind Farms

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Abstract

It is a crucial requirement to utilize an economical battery capacity for the wind energy conversion system. In this paper, the optimal BESS capacity is determined for the wind farm whose dispatched power is assigned by the min-max dispatching method. Based on a lifetime cost function that indicates the BESS cost spent to dispatch 1kWh wind energy into grid, the battery capacity can be optimized so as to obtain the minimum system operation cost. Moreover, the battery state of charge (SOC) is also managed to be in a safe operating range to ensure the system undamaged. In order to clarify the proposed optimizing method, a 3MW permanent magnet synchronous generator (PMSG) wind turbine model and real wind speed data measured each minute are investigated.

1. Introduction

In order to mitigate the wind power fluctuation, the battery energy storage system (BESS) is utilized as the most feasible solution [1]. Fig. 1 illustrates a wind energy conversion system with BESS. Wind energy captured by turbine blades is converted into electric power P_w through a PMSG. The output of the generator is rectified and stored in the dc-link where the BESS is connected via a bidirectional dc-dc converter (CONV3). Under assumption that the power losses in the system is negligible, the dispatched power P_d into the grid is outcome of subtracting the BESS power P_b from the wind power P_w or $P_d = P_w - P_b$. Obviously, by regulating the charged/discharged power P_b, the dispatched power P_d can be controlled thereby overcome the fluctuation problem of wind power. However, because of economic problem, it is a crucial requirement to utilize an optimal battery capacity [2].

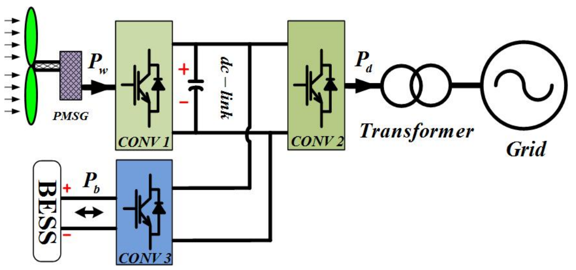

Fig. 1 A wind farm configuration with BESS.

In this paper, we propose a method to determine the optimal battery capacity. By defining a lifetime cost function and using the min-max dispatching power strategy, the optimal battery capacity is determined after two steps. First, the minimum battery capacity, which is capable of compensating wind power fluctuation, is defined and considered as a basic capacity. The lifetime cost function, which indicates how much money spent on BESS to integrate 1kWh of electricity to grid, is defined. Subsequently, in second step, by increasing the battery capacity from the basic volume, the minimum lifetime cost function value is identified and thus the optimal battery capacity is designated. To clarify the fact that the proposed method is economic and optimal, a numerical example with 3MW-PMSG wind turbine (WT) model is examined through MATLAB software.

2. Optimization of BESS Capacity

As a vital step on the WT-BESS planning and design, determination of the BESS capacity decides how large battery needs to be utilized with considering not only the sufficiency to compensate the unsteady wind power but also the cost to economically operate the system. Thanks to several advantages such as the ability of communication with transmission system operator (TSO), the ease control of the BESS converter, and the improvement of BESS life time, the min-max dispatch strategy is adopted in this study [2].

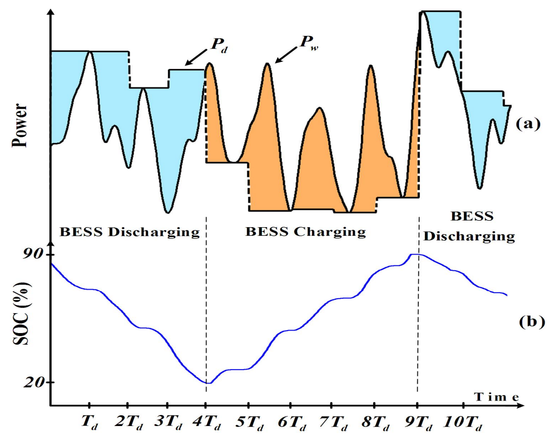

Fig. 2 (a) The min-max dispatch strategy. (b) SOC of battery.

As illustrated in Fig. 2(a), the dispatched power to grid is assigned as maximum or minimum value of the wind power during the dispatching time interval T_d. When the dispatched power is set to be the maximum wind power, the BESS power is negative or the battery is being discharged to fulfill a gap between the dispatched power P_d and the wind power P_w. This process continues until the SOC of battery is decreased to its lower limit (20%) as shown in Fig. 2(b). Once the battery status is shifted to the charging phase, a part of wind power used to charge the battery results in the dispatched power smaller than the wind power. In order to make the system operate effectively, the dispatched power should be assigned at the minimum level of the wind power. The battery is charged until its SOC reaching to the upper limit (90%). In this dispatching principle, it is clear that the battery is managed to be in charged or discharged status during the time interval T_d, hence the total number of full charge/discharge cycles can be counted during system operation.

2.1 The Basic Level of BESS Capacity

According to the min-max dispatch principle, the BESS is only charged or discharged in a dispatch time interval T_d. Therefore, the BESS capacity must be adequate to guarantee that at any dispatch interval the battery is not overcharged or exhausted, then the minimum level of BESS capacity must be defined as a basic level. Based on the given long-term wind speed data in a time T, the basic level is determined by following steps. Firstly, the wind power data during the interval T is divided into N sets, then the each data set has a period T_d (i.e., $T=N*T_d$). Subsequently, in the BESS discharging phase, N sets of the BESS discharging energy are calculated by integrating the BESS discharging power over one T_d. It is noted that the BESS discharging power is outcome of subtracting the wind power from its maximum level in a dispatch time T_d as shown in Fig. 2. The BESS energy capacity required in the discharging phase should be bigger than the greatest energy level during BESS discharge. Next, similarly, the BESS energy capacity should be higher than the maximum charging energy level in the charging phase. By comparing these two BESS capacities, the basic level of the BESS capacity is found out.

2.2 The Optimal BESS Capacity

The min-max dispatching strategy causes a tradeoff between battery lifetime and the BESS cost. As shown in Fig. 2, once the battery capacity is increased, time period of discharging and charging phase can be prolonged, and the battery life span is extended. However, this increase results in an expensive battery investment cost. Therefore, the design objective should consider an optimal BESS capacity so as to minimize the system operating cost or to make the wind farm work economically. In this study, a lifetime cost function (LTC) indicating the system operating price is introduced in order to find an optimal battery capacity:

$$LTC = \frac{\alpha E_b}{\sum_T P_d T_d} \frac{c}{C_r} \quad (1)$$

where α is the battery energy cost (*\$/kWh*) and is used to calculate the total cost of the BESS with a capacity rating E_b. Considering the system operating in a time T, the first term in denominator of LTC means the total energy delivered to the grid and c denotes the total charge/discharge cycles of the battery. Whereas, with a given depth of discharge of battery, the maximum charge/discharge cycles that the battery can be handled in its lifespan is denoted as C_r. When the battery capacity is given and the min-max dispatching method is adopted, all components in (1) are defined so that the LTC can be computed. As a result, by increasing the battery capacity from the basic level, we are able to identify the optimal BESS capacity that allocates the LTC at the minimum value.

3. Numerical Example

This section presents a numerical example in order to illustrate the BESS capacity determination approach that introduced in previous section. The wind speed profile in two years 2009 and 2010 is taken from [3] and is converted into power data by using a 3MW PMSG wind turbine model. It means that the system is evaluated in a time interval T=2 years with the dispatching time $T_d = 0.5h$. Deep-cycle technique is adopted here, but the battery SOC is controlled within a safe range 0.2-0.9. In [4], the battery specification in connection with the price and the lifelong charge/discharge cycles are given as $\alpha = 685.5$ \$/kWh and $C_r = 1500$ cycles, respectively. By following steps presented in Section 2.1, the basic battery capacity for the given system is determined to be 843.7kWh. Next, as discussed in section 2.2, the battery capacity is increased from the basic level to identify how large BESS is in order to obtain minimum LTC function. The BESS capacity leading to the LTC minimum is an optimal BESS capacity for system. Fig. 3 shows the LTC function value corresponding to the BESS capacity which is normalized through the basic battery capacity. It is recognized that the optimal BESS capacity is obtained at four times of the basic capacity level or 4x843.7=3.375MWh and the minimum LTC value is 4.27 cents/kWh. From the optimal BESS capacity, the SOC of battery is managed and kept in a safe range with 0.2-0.9 as shown in Fig. 4.

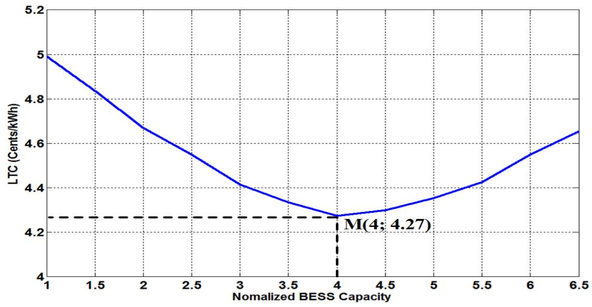

Fig. 3 Lifetime cost function versus normalized BESS basic capacity.

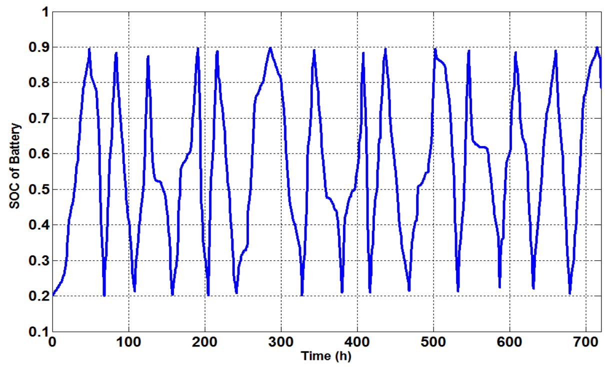

Fig. 4 SOC of BESS performance with the optimal capacity.

4. Conclusion

The min-max dispatch method poses several advantages and is proper to cooperate with TSO in the modern electricity system. This paper introduces how to determine the optimal BESS capacity by means of minimizing a lifetime cost function. In this method, the basic capacity of BESS is considered to ensure the battery size enough to handle the min-max dispatch strategy. Subsequently, by increasing the BESS capacity from this basic level, the system lifetime cost is computed. The optimal capacity is obtained from the minimum lifetime cost. A numerical example is carried out to demonstrate the proposed determination method.

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